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Artificial lighting triggers the presence of urban spiders and their webs on historical buildings

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(Article begins on next page)

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Title: Artificial lighting triggers the presence of urban spiders and their webs on historical buildings

Article Type: Research paper

Keywords: urban ecology; digital image analysis; light pollution; Araneae; synanthropic species; aesthetic nuisance

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Abstract: Different spider species living in the urban environment spin their webs on building facades. Due to air pollution, web aggregations entrap dirt particles over time, assuming a brownish-greyish colouration and thus determining an aesthetic impact on buildings and street furniture. In Europe, the most common species causing such an aesthetic nuisance is *Brigittea civica* (Lucas) (Dictynidae). In spite of the socio-economical relevance of the problem, the ecological factors driving the proliferation of this species in the urban environment are poorly described and the effectiveness of potential cleaning activities has never been discussed in scientific literature. Over one year, we studied the environmental drivers of *B. civica* webs in the arcades of the historical down-town district of Turin (NW-Italy). We selected a number of sampling plots on arcade ceilings and we estimated the density of *B. civica* webs by means of digital image analysis. In parallel, we collected information on a number of potential explanatory variables driving the arcade colonization, namely artificial lighting at night, substrate temperature, distance from the main artificial light sources and distance from the river. Regression analysis showed that the coverage of spider webs increased significantly at plots with higher light intensity, with a major effect related to the presence of historical lampposts with incandescent lamps rather than halogen lamps. We also detected a seasonal variation in the web coverage, with significant higher values in summer. Stemming from our results, we are able to suggest good practices for the containment of this phenomenon.



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May 07th, 2018

Dear Dr Xiang,

we hereby submit the revised version of manuscript LAND-D-18-00321 entitled “**Artificial lighting triggers the presence of urban spiders and their webs, causing an aesthetic damage to historical buildings**” intended for publication in *Landascape and Urban Planning*.

We thank you for handling our submission and spending time in evaluating it. In this revision, we have took into account all minor corrections suggested by referee 2 and proof-read it once more.

We confirm that the work is all original research carried out by the authors, all authors agree with the contents of the manuscript and its submission to the journal, no part of the research has been published in any form elsewhere, and the manuscript is not being considered for publication elsewhere.

Yours,

Dr Marco Isaia

On behalf of all co-authors

REBUTTAL LETTER FOR

LAND-D-18-00321

**'Artificial lighting triggers the presence
of urban spiders and their webs on historical buildings'**

Reviewer #2: Landscape and Urban Planning MS 18-0321

This seems to be a respectable contribution suitable for publication. It is a nice combination of science addressing a real world problem. It also is a relatively clean paper. I usually find lots of mistakes in manuscripts that I review but this one had few errors. One caveat is that I have very limited statistical background so the editor needs to make sure that someone with statistical ability reviews the paper.

RESPONSE: Thank you for spending time to review our manuscript and for you very positive attitude toward it.

There are several instances of misspelling the spider family name as "Dyctinidae" which needs correcting (lines 45, 505, 506)

RESPONSE: Corrected.

line 47: cited as Hertel 1969 in the text but 1968 in the reference section

RESPONSE: Corrected – the right one was 1968.

line 217: citation is "XXXXXXX" but is probably Hanggi which is not cited in the paper and is also 2016

RESPONSE: Actually, this is not a mistake. From the journal's guidelines (see highlight in colour):

"Landscape and Urban Planning uses a double-blind review process, and to ensure anonymity the manuscript file must not include any self-referencing, logos, headers or any other type of information or formatting that might reveal the identify or affiliation of any of the authors. Acknowledgements should not be included in the manuscript file and must be uploaded as a separate file. See Section 3.9.7 below. Self-references that must be included must not be obvious in revealing any authors' identify and should refer to the authors' work only indirectly (e.g., "This work builds upon procedures developed by Smith (2010)"; NOT "I build upon my previous work (Smith, 2010)..."). To further ensure anonymity, authors may choose to temporarily remove self-citations from the reference list and mask in-text references (e.g., "(XXX, 2009 masked for blind review)"), then restore the proper citation when the manuscript is accepted. Although such an approach better respects the integrity of the blind review process, authors must weigh the removal of a citation against the need for reviewers to evaluate the credibility of your work."

On the other hand, we now reference the missing reference in the text (Hanggi).

line 62: change "environment" to "environments"

line 152: insert a space in "Photo#2"

line 175: change "generated" to "generate"

line 270: change "them" to "themselves"

line 287: I would change "Southern" to "southern"

line 350: change "spider" to "spiders"

line 352: I would change "Southern" to "southern"

line 484: insert a space in "seriesmodel"

56 line 541: many other citations have a long list of authors, whereas this one just has the first author and et al.
57 line 590s: Vetter paper should be listed before Vitousek
58 line 620: add a space in "typeanalyses"
59
60 **RESPONSE: Done.**

1 **Artificial lighting triggers the presence of urban spiders and their webs on historical**
2 **buildings**

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1. Spider web aggregations affect the aesthetic value of historical building
2. We studied the ecological factors driving the abundance of spider webs on historical arcade ceilings
3. Web density was estimated using an innovative photographic-based methodology
4. By attracting prey, incandescent artificial lighting is the major factor driving of the increase of spider webs
5. Changing the lighting system type may help in reducing this problem

1 Artificial lighting triggers the presence of urban spiders and their webs on historical 2 buildings

5 Abstract

7 Different spider species living in the urban environment spin their webs on building
8 facades. Due to air pollution, web aggregations entrap dirt particles over time, assuming a
9 brownish-greyish colouration and thus determining an aesthetic impact on buildings and
10 street furniture. In Europe, the most common species causing such an aesthetic nuisance
11 is *Brigittea civica* (Lucas) (Dictynidae). In spite of the socio-economical relevance of the
12 problem, the ecological factors driving the proliferation of this species in the urban
13 environment are poorly described and the effectiveness of potential cleaning activities has
14 never been discussed in scientific literature. Over one year, we studied the environmental
15 drivers of *B. civica* webs in the arcades of the historical down-town district of Turin (NW-
16 Italy). We selected a number of sampling plots on arcade ceilings and we estimated the
17 density of *B. civica* webs by means of digital image analysis. In parallel, we collected
18 information on a number of potential explanatory variables driving the arcade colonization,
19 namely artificial lighting at night, substrate temperature, distance from the main artificial
20 light sources and distance from the river. Regression analysis showed that the coverage of
21 spider webs increased significantly at plots with higher light intensity, with a major effect
22 related to the presence of historical lampposts with incandescent lamps rather than
23 halogen lamps. We also detected a seasonal variation in the web coverage, with
24 significant higher values in summer. Stemming from our results, we are able to suggest
25 good practices for the containment of this phenomenon.

27 **Keywords:** urban ecology; digital image analysis; light pollution; Araneae; synanthropic
28 species, aesthetic nuisance

29 1. INTRODUCTION

30

31 Environmental modifications driven by urbanization have a significant effect on biodiversity
32 (Güneralp & Seto, 2013; Seto, Gueneralp, & Hutyra, 2012; Vitousek, 1997), driving large
33 changes in species abundances and distributions within the original biological communities
34 (McKinney, 2008). Whilst urbanization is considered to be a major determinant of
35 biodiversity loss (Grimm et al., 2008; Newbold et al., 2015), a number of organisms are
36 able to coexist alongside us in urban environments (e.g., Aronson et al., 2014; Bertone et
37 al., 2016; McKinney, 2002). Owing to their high ecological plasticity (Turnbull, 1973),
38 several species of spiders are able to dwell in cities, representing an important component
39 of the urban wildlife (McIntyre, 2000; Shochat, Stefanov, Whitehouse, & Faeth, 2004;
40 Taucare-Ríos, Brescovit, & Canals, 2013). With the exception of some species of medical
41 importance (e.g. Isbister et al., 2005; Sams et al., 2001; Vetter & Isbister, 2008), urban
42 spiders usually have little socio-economic impacts and often remain unnoticed. A
43 remarkable exception is found in those spider that due to their webs may cause aesthetic
44 alterations to buildings facades — see discussion in Nentwig (2015).

45 In Europe, one of the most noticeable species causing aesthetic nuisance to
46 buildings is *Brigittea civica* (Lucas) (Araneae: Dictynidae) (Figure 1A) (Samu, Jozsa, &
47 Csànyi, 2004). This is a small cribellate spider (body length 2.3–3.5 mm; Nentwig, Blick,
48 Gloor, Hänggi, & Kropf, 2018) of South European origin (Hertel, 1968), which spins a
49 circular, tangled cribellate cobweb on flat surfaces (Billaudelle, 1957; Krumpálová, 2001).
50 Although being relatively small in size (ca. 5 cm in diameter), cobwebs of *B. civica* may
51 occur at very high density on wall facades and can persist for long periods of time (Figure
52 1B–D). The fact that multiple individuals are able to coexist and spin their cobwebs at a
53 very close distance to one another can be explained in light of the peculiar behaviour of *B.*
54 *civica*, with different individuals being able to share prey without fighting each other
55 (Billaudelle, 1957). Due to air pollution, these large web aggregations entrap dust and dirt

56 particles over time, assuming a brownish-greyish coloration and thus significantly reducing
57 the aesthetic value of buildings (Havlová & Hula, 2010; Kostanjšek & Celestina, 2008;
58 Nedvěd et al., 2011; Novotný, Hula, & Niedobová, 2017; Samu et al., 2004; Figure 1D, E).

59 The factors determining this phenomenon are as yet poorly described, and thus no
60 good practices have been put forward to address this problem and to maximize the
61 effectiveness of potential cleaning activities. To the best of our knowledge, the only study
62 referring to habitat selection by *B. civica* was conducted by Samu et al. (2004) in urban
63 environments in Hungary. The authors demonstrated quantitatively how web density is
64 significantly higher in facades with a southern exposure and sheltered to external
65 weathering (especially rain), whereas they found no clear pattern in the selection of
66 different surface-types.

67 Because of its artistic heritage from one side and of its predominantly
68 Mediterranean climate suitable for *B. civica* on the other, Italy is potentially among the
69 most affected countries by this issue. In several Italian heritage cities, webs of this spider
70 are found on churches, arcades, palaces and other historical buildings exploited for
71 touristic purposes, resulting in possible economic impacts connected to the cleaning
72 activities aimed at removing the webs.

73 We conducted a one-year field study to identify the environmental factors driving the
74 proliferation of *B. civica* webs in the arcades of the historical down-town district of Turin
75 (NW-Italy) (Figure 1E). Observations made by the authors during a preliminary site
76 inspection, and similar recorded observations published by Samu et al. (2004), lead to an
77 initial prediction that i) the density of webs is significantly higher in the vicinity of artificial
78 lighting systems and in other areas with high illuminance. Moreover, given that webs of *B.*
79 *civica* may last for long time on the surfaces, we further hypothesize that ii) webs are
80 present through the year, but there should be variation in their density connected with the
81 phenology of the species. In particular, increases in the density of webs may be expected

82 right after the breeding period for this species, approximately from April to June
83 (Kostanjšek & Celestina, 2008; Nentwig et al., 2018; Wiehle, 1953).

84 2. MATERIAL & METHODS

85

86 2.1 Study area

87 This study was conducted in the municipality of Turin (Torino), NW-Italy (45° 04' N, 7° 42'
88 E). The city has a long history, testified by the traditional orthogonal plant of the ancient
89 Roman camps ("*castrum*"), and the remarkable Baroque architecture, which was
90 developed under the Duchy of Savoy (1416–1860). The down-town district of Turin has 18
91 kilometres of historical Baroque arcades ("*portici*"), mostly interconnected with each other,
92 making it one of the largest pedestrian areas in Europe. Arched ceilings represent suitable
93 habitats to *Brigittea civica* spiders, being naturally sheltered from rains, direct solar
94 irradiation, and air currents (Billaudelle, 1957; Samu et al., 2004). As a result, most
95 arcades ceilings are heavily colonized by *B. civica* cobwebs (Figure 1B–D). In order to
96 improve the aesthetic value of the historical district, the competent authorities promoted
97 the cleaning of the arcades in 2006, when the city hosted the XX Olympic Winter Games.

98 We conducted our study in the heart of the historical down-town district, on the
99 arcades connecting Piazza Vittorio Veneto to Piazza Castello all along Via Po, for
100 approximately 2 kilometres. In this area, arcades are predominantly Serlian-type arches,
101 ranging from 3 to 5 m in height (Figure 1E). The majority of the arcades have vaulted
102 ceilings, with some exceptions (coffered ceilings) along a small stretch of Via Po, which we
103 did not consider in this analysis. At night, arcades are illuminated by historical lampposts
104 with incandescent lights and/or halogen lamps, which are installed at different heights.

105

106 2.2 Data collection

107 We conducted three monitoring sessions over one year (Winter: 10 Dec 2016; Spring: 30
108 Apr 2017; Summer: 7 Jul 2017), at night. In order to provide a homogeneous coverage of
109 the entire study area, we selected seventy-two arcades as basic sample units,

110 approximately equidistant. All sampling plots were georeferenced. Within each basic
111 sample unit, at each survey we randomly identified one sampling plot of 1.0 x 0.7 m on a
112 flat area of the ceiling (i.e. avoiding angles and cracks and crevices in the plaster). Using
113 this study design, we were able to control for substrate type (all arcade ceilings are
114 characterized by the same plaster type) and general exposure to external weather (all
115 arcades are protected by rains, direct solar irradiation, and air currents).

116 We conducted the monitoring by means of a photography-based methodology
117 (Figure 2), by taking two photos of each sampling plot in order to estimate the density of
118 *Brigittea civica* webs (photo #1) and the intensity of artificial lighting illuminating the wall
119 surface of the plot (photo #2). Full details on the calculation of these variables are given in
120 the section "*Photographic analysis*". At each survey, we further measured the substrate
121 temperature with an infrared thermometer at the centre of the sampling plot, and we
122 calculated the linear distance from 1) the closest historical lamppost (incandescent lighting
123 system) and/or 2) the closest halogen light (Figure 2). The distance of each sampling plot
124 from the Po River, which is flowing close to the study area (see Figure 3), was further
125 calculated in a GIS environment (ArcView 3.3 ESRI). This latter variable was introduced to
126 account for the potential influence of local microclimatic factors related to the proximity of
127 water on web abundance and insect prey availability — e.g. as observed in other web
128 weaver spiders (Akamatsu, Toda, & Okino 2004, Gillespie, 1987; Kleinteich, 2010).

129 **2.3 Photographic analysis**

130 We carried out the photographic analysis in National InstrumentsTM LabVIEW environment
131 (Elliott, Vijayakumar, Zink, & Hansen, 2007). In order to obtain a value representing the
132 web coverage of each plot, we acquired a photo of the plot (photo #1) in raw mode with a
133 Nikon D810 camera equipped with a Nikon sb910 flash; the image was then converted to
134 16 bit greyscale. Initially we conducted a set of exploratory tests, applying different pixel
135 thresholds for converting the 16 bit greyscale image into a black and white (B/W) image.
136 The aim of the B/W conversion was to recolour the pixels depicting webs of *Brigittea civica*
137 in black and the remaining pixels in white, thus allowing an estimation of the web coverage
138 within the plot. After the preliminary trial, we set the B/W conversion threshold at 49000
139 (where 0 is black and 65535 is white), which proved to be the best trade-off value to
140 separate the webs from other features of the surface within the image — i.e. dust particles
141 on the substrate or darker areas due to the natural ruggedness of the ceiling plaster. We
142 used this fixed threshold for converting all images into B/W, and we summed up the
143 number of black pixels via an automated function.

144 Despite the evaluation of the light intensity that reaches a surface is normally
145 performed directly using a photoradiometer, in our case this resulted highly impractical due
146 to the height of the arcades and the number of plots. Starting from the assumption that the
147 intensity of the light reflected by a surface is correlated with the intensity of the lighting
148 source, we used an evaluation method based on the acquisition of the reflected light with a
149 camera. By choosing surfaces having more or less the same colour and the same surface
150 morphology, and by setting up a fixed exposure time and no flash, it is possible to use the
151 acquired image as an indirect measure of the light intensity of the plot. Consequently,
152 images with low values of R, G and B channels correspond to low values of light intensity
153 reaching the surface, while high values of R, G and B channels correspond to high values
154 of light intensity. For this calculation, we acquired a second image of the plot (photo #2)

155 focusing on a web-free surface (Figure 2). Photo #2 was taken in raw mode with a Nikon
156 D3X camera without flash and using a fixed exposure. We converted the digital image to a
157 16 bit RGB, and we derived the histogram representing the distribution of the overall pixel
158 values (range 0 – 65535). We used the modal value — i.e., the most recurrent value in the
159 image — as an indirect measure of the artificial light intensity that illuminated the
160 photographed surface. We repeated the same operation for each of the RGB channels in
161 order to explore possible relationships between the web coverage and different colours of
162 light.

163

164 **2.4 Regression analysis**

165 We studied the relation between environmental factors and *Brigittea civica* web coverage
166 by performing a regression-type analysis (Zuur & Ieno, 2016) in R (R core team, 2017).
167 We expressed the dependent variable as the counts of black pixels (i.e. pixel covered with
168 webs) within photo #1 — hereinafter “web coverage” (WEB). We selected the following
169 covariates (explanatory variables) as potential drivers of the web coverage in the sampled
170 plots: distance from the river (Dst; continuous variable), substrate temperature (T°;
171 continuous variable), sampling session (Sampling; categorical variable of three levels),
172 artificial light intensity (ILL; continuous variable calculated from photo #2), Red, Green and
173 Blue light components (R, G, B, respectively; continuous variables calculated from photo
174 #2), distance from the nearest historical lamppost (Dst_lamp; continuous variable) and
175 distance from halogen light sources (Dst_halo; continuous variable). In order to account for
176 potential density-dependent effects in driving the web coverage (i.e. spatial relationships
177 among webs), we further included a variable reflecting the intercrossed distance of each
178 plot from the others (InterDst; continuous variables). To generate this variable, we
179 calculated the distance matrix of each sampling plot using the spatial coordinates of the
180 plots, and derived the mean distance of each plot from the others. We tested for spatial

181 autocorrelation in web coverage *via* Moran's I test in the *ape* R package (Paradis, Claude,
182 & Strimmer, 2004), using the Gittleman and Kot (1990) method.

183 We initially explored the dataset using the standard protocol described by Zuur,
184 Ieno, and Elphick (2010). We constructed Cleveland' dotplots to assess the presence of
185 outliers within the dataset. We investigated multi-collinearity among explanatory variables
186 by means of scatterplots, Pearson correlation tests (r), by setting the threshold for
187 collinearity at $r > |0.7|$ (Zuur, Ieno, Walker, Savaliev, & Smith, 2009). Boxplots were also
188 constructed to graphically assess collinearity between continuous and categorical
189 variables.

190 To model the response of the web coverage to the explanatory variables, we initially
191 fitted a Poisson generalised linear model (GLM), including all non-collinear covariates of
192 interest. In order to test for the potential effect of the different light source illuminating the
193 plot, we allowed for interactions between the artificial light intensity and the distance from
194 the different light sources ($\text{Dst_lamp} * \text{ILL}$; $\text{Dst_halo} * \text{ILL}$). The Poisson GLM was highly
195 over-dispersed [dispersion statistic (DS)=600.95], and thus a negative binomial GLM was
196 considered (Zuur et al., 2010). We fitted the negative binomial GLM in the *MASS* R
197 package (Venables & Ripley, 2002). Over-dispersion in the negative binomial GLM was
198 minimal (DS=1.62), so we chose this error distribution in all subsequent analysis.

199 Once we fitted the initial negative binomial GLM including all the covariates and
200 interactions of interest, we performed model selection in order to select which variables
201 should be included in the final model (Johnson & Omland, 2004). We used a stepwise
202 backward elimination procedure, whereby we progressively excluded variables and
203 interactions from the model according to the corrected Akaike information criterion for finite
204 sample size (AICc values; Burnham & Anderson, 2002; Hurvich & Tsai, 1989). We
205 reiterated the procedure until we obtained a Minimum Adequate Model (MAM) including

206 only significant variables. We conducted model selection using the *MuMIn* R package
207 (Bartoń, 2017).

208 Model validation was conducted on the MAM (Zuur et al., 2009). In particular, we
209 tested it for over-dispersion, we constructed standard validation plots using model
210 residuals and we investigated the existence of possible non-linear responses of our
211 covariates by means of generalized additive models (GAMs). GAMs were fitted with the
212 *gam* R package (Hastie, 2013), using the same model structure identified during model
213 selection.

214

215 **2.5 GIS analysis**

216 For each sampling plot, we predicted the value of web coverage using the most
217 appropriate model structure supported by the observations derived from the model
218 selection. In order to provide a graphical representation of the investigated phenomenon in
219 the study area, we interpolated these predicted values in a GIS environment using the
220 methodology detailed in Mammola and Isaia (2016). For this analysis, we drew the vector
221 layer of the arcades on the raster topographical map of the study area, and we
222 interpolated the projected values for each sampling plot relative to each sampling session.
223 For the interpolation, we used an Inverse Distance Weighted function (IDW) using a
224 sample of 12 plots (power 2) to estimate cell values and obtain the renderings of the model
225 prediction.

226 3. RESULTS

227

228 Following the initial data exploration (Zuur et al., 2010), we dropped R, B and G light
229 components from the GLM analysis, being collinear with artificial light intensity (all Pearson
230 $r > 0.9$). Moreover, we dropped the distance from the river (Dst), being collinear with the
231 inter-plot crossed distance (InterDst) and we excluded substrate temperature (T°) from the
232 analysis, being collinear with the sampling session. We further applied a log-
233 transformation to artificial light intensity to achieve homogenization of its distribution (Zuur
234 et al., 2009), and removed one outlier from the dataset.

235 According to model selection (Table 1), the MAM had the following structure: $WEB \sim$
236 $\log(ILL) \times Dst_lamp + Sampling$. Specifically, we found a positive and significant
237 interaction between the artificial light intensity and the distance from the historical
238 lamppost, whereby higher web coverage was predicted at higher values of light intensity
239 and in the vicinity of historical lamppost. The effect of this interaction can be visualized in
240 Figure 4. We also detected a pattern of seasonal variation in the density of webs on the
241 arcades, with significantly higher predicted values in summer with respect to spring
242 (reference category). Coverage in winter was not significantly different from the reference
243 category (Figure 4). Estimated regression parameters and p values are reported in Table
244 2, and a graphical representation of the model prediction is shown in Figure 3.

245 There was a significant spatial association in the web coverage among plots
246 (Moran's I test, observed= -0.022 ; expected= -0.006 ; sd= 0.005 $p < 0.05$). However, this
247 effect was not recovered in the regression analysis, given that the variable InterDST was
248 not significant and thus dropped from the model during the backward elimination model
249 selection procedure. Spatial association of webs can be visualized graphically in Figure 3
250 (note the conditional size of the dots representing the plots).

251 4. DISCUSSION

252

253 The two strongest predictors of the web coverage of *Brigittea civica* in the historical
254 arcades of Turin were the intensity of artificial light and the distance from the nearest
255 historical (incandescent) lamppost. Moreover, we found a variation in the web coverage
256 with respect to the sampling session (Figure 3). It is well demonstrated that artificial
257 illuminance plays an important ecological role in urban settings (e.g., Gaston & Bennie,
258 2014; Gaston, Bennie, Davies, & Hopkins 2013; Sanders & Gaston, 2018) and other
259 studies have reported about the significant association between different urban species
260 and artificial lighting (e.g. Frank, 2009; Heiling, 1999; but see Voss, Main, & Dadour,
261 2007). As far as *Brigittea civica* is concerned, Samu et al. (2004) reported that (p. 355):
262 "[...] casual observation [...] showed that [B. civica] webs were aggregated around artificial
263 lights." Our work provides statistical support to this observation, as we demonstrated that
264 the web coverage of the plots was significantly higher in the plots where artificial light was
265 more intense.

266 It was observed that spiders thriving in urban habitats may benefit from increased
267 trophic resources in cities (Lowe, Wilder, & Hochuli, 2016; Trubl, Gburek, Miles, &
268 Johnson, 2012; Voss et al., 2007). Based upon this premise, the relationship between web
269 coverage and artificial light that we observed, could be explained as a function of the
270 higher prey availability found in the nearby of light sources (Heiling, 1999). The attraction
271 of aerial and terrestrial arthropods to artificial lighting is indeed a well-documented
272 phenomenon (Davies, Bennie, & Gaston, 2012; Eisenbeis, 2006; Frank, 2006; Shimoda &
273 Honda, 2013). It has been shown that *B. civica* is able to feed upon a wide range of small
274 flying insects — including dipterans, but also flying ants, small lepidopterans and aphids.
275 Also, if previously starved of food, these spiders are able to feed upon prey nearly three

276 times bigger than themselves (Billaudelle, 1957). This wide range of potential prey is
277 expected to be available in the areas surrounding street lights (Davies et al., 2012).

278 Our data also demonstrate that the type of light source is important in explaining the
279 coverage of webs. In particular, spider webs were more abundant in the vicinity of
280 incandescent historical lampposts (Figure 3) rather than halogen lamps. We assume that
281 the light emitted by lampposts has its greater effects on attracting spiders due to its higher
282 potential of attracting insect prey. It is well-documented that nocturnal insects are able to
283 see ultraviolet radiation, being often attracted to light sources that emit large amounts of
284 UV radiation (Shimoda & Honda, 2013). At the same time, different light spectra have
285 different attraction potential to nocturnal arthropods (e.g. Longcore et al., 2015), with
286 incandescent lights often attracting most nocturnal insects (Justice & Justice, 2016). This
287 would convincingly explain the interaction we observed between light intensity and the
288 distance from the incandescent light sources.

289 One could argue that the incandescent artificial lighting system may affect the
290 distribution of the spiders because of the general influence on thermal conditions, rather
291 than because of its light spectrum. In fact, there should be higher ambient temperature in
292 the vicinity of lights, offering a more favourable habitat for a southern European species
293 such as *B. civica*. However, we rejected this alternative explanation given that the
294 temperature of the substrate was only limitedly anti-correlated with the distance from the
295 incandescent artificial lighting system ($r = -0.26$).

296 There is evidence indicating that spiders may be able to recognise the quality of
297 foraging patches and change web site on the basis of prey availability (e.g., Enders, 1977;
298 Gillespie & Caraco, 1987; Harwood, Sunderland, & Symondson, 2001; but see Vollrath,
299 1985). Conversely, it may also be that habitat patches with higher light intensity, and thus
300 higher prey availability, are not actively selected by the spiders, but simply support larger
301 colonies of spiders, due to their more favourable condition. It stands to reason that the

individual fitness of a spider should be higher in a prey-rich rather than in prey-poor habitat patch. However, further studies are needed to determine whether the optimal patches are actively selected by the spiders, or if the higher web coverage found in the vicinity of incandescent lampposts is the actual results of a higher persistence of the local population.

It is likely that the effect of artificial lighting was particularly clear-cut in our case because, through the design of the study, we were able to exclude other confounding factors. It has been shown that *B. civica* avoids areas exposed to rains, winds and direct solar irradiation (Billaudelle, 1957; Samu et al., 2004). By using our study design (all plot in sheltered arcades), we were able to exclude these factors from the analysis. Moreover, we deliberately avoided plots with significant cracks and crevices in the plaster, which are preferentially selected as supporting framework for the construction of webs and may thus influence the fine distribution of this species.

4.1 Management implications

It has been argued that there is not an easy solution to the contamination of urban wall surfaces by spider webs of *Brigittea civica*, mainly because this species does not show a selective preference for a particular wall material or painting (Samu et al., 2004). As far as we are aware, the only method so far implemented to deal with this issue is the mechanical removal of the spider webs from the wall surfaces. Whilst the mechanical removal is certainly effective, such methodology is rather costly, time consuming and problematic, especially in the case of high buildings. Secondly, the mechanical removal only represents a temporary remedy to the problem, needing to be reiterated over time.

There are three general findings relevant to the management of building surfaces arising from this work. First, the timing of the mechanical cleaning can be important. Whilst this may seem self-evident, we suggest that it is important to consider carefully the

328 phenology of the species when planning the cleaning activities. We documented a higher
329 prevalence of webs during the warm seasons (Figure 4). In particular, a higher web
330 coverage was observed in summer, at the end of the breeding season of *B. civica*
331 (Kostanjšek & Celestina, 2008; Nentwig et al., 2018; Wiehle, 1953). This observation
332 suggests that, in order to maximise the effect of the mechanical removal of the webs, one
333 should perform the cleaning after the summer peak of density.

334 Second, we showed that the incandescent artificial lighting systems illuminating
335 most of the arcades in our study area is the main trigger of the increase of the web
336 coverage (Figure 4). Thus, a renovation of the artificial lighting illuminating in the down-
337 town districts of heritage cities towards halogen or light emitting diode (LED) lights may
338 provide a near-permanent solution to this problem, or it may at least contribute to mitigate
339 the contamination. According to our results, arcades and building facades should become
340 a less attractive habitats for spiders, thereby reducing the aesthetic nuisance caused by
341 the webs.

342 Third, casual observations during this study revealed that cracks and crevices in the
343 plaster are preferentially used as supporting framework for the construction of webs.
344 Maintaining an intact plaster, at least in the touristic areas, will likely help in reducing the
345 intensity of the phenomenon.

346 Ultimately, it can be argued that heavy traffic exacerbates the phenomenon, given
347 that webs became more visible due to air pollution — see argumentation in Samu et al.
348 (2004). Pedestrian areas have been introduced in most of the historical down-town
349 districts of cities all around the world, with the aim of increasing commercial and touristic
350 activities, meanwhile reducing pollution to preserve historical sites (Pagliaria & Biggiero,
351 2013). Accordingly, an increase of pedestrian areas associated to a reduction of the local
352 air pollution in down-town districts will, in turn, limit the aesthetic impact associated with *B.*
353 *civica* webs.

354

355 **4.2 Significance statement**

356 One may argue that the results of this study might not be applied to spiders more widely
357 and that *Brigittea civica* might represent only a very specific case. Still, it is worth noting
358 that, despite being of southern European origin, this species has been spreading
359 northward during the last few years. Currently, *B. civica* reaches central Siberia and central
360 Asia (Buchar & Růžička, 2002; Zamani & Mozaffarian, 2017). Recent evidence indicate
361 that the species is much more common than was previously known; for instance, in
362 Central Europe it is likely that its presence has been underestimated (data from Czech
363 Republic; Novotný et al., 2017; see also discussions in Hänggi & Straub, 2016). Moreover,
364 the spider was recently found in North America (World Spider Catalog, 2018) and South
365 Africa (Foord, 2014), which poses additional concerns in light of the potential economic
366 importance of the potential aesthetic damage caused by this species.

367 Moreover, this study exemplifies a methodological approach that is efficient and
368 inexpensive, and thus that can be easily reproduced in other cases. More studies similar to
369 this one would be useful when considering other species which are known to have
370 potentially negative aesthetic impacts, or that may even cause potential structural
371 damages. For instance, the photography-based methodology herein described can be
372 easily used to estimate the density of other organisms which may occur at high densities
373 — even forming biofilms — on wall surfaces, especially lichens, mosses, and fungi (e.g. de
374 los Ríos et al., 2009 Gaylarde & Morton, 1999; Lisci, Monte, & Pacini, 2003).

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648 **TABLES**

649 **Table 1.** Model selection according to the corrected Akaike criterion for finite sample size (AICc; Burnham &
 650 Anderson, 2002; Hurvich & Tsai, 1989). Models are ordered from the most to the least appropriate.
 651

Model	df	AICc	Δ AICc	wi
y~log(ILL)*Dst_halo + log(ILL)*Dst_lamp + Sampling + InterDst	10	2362.37	3.41	0.08
y~log(ILL)*Dst_halo + Dst_lamp + Sampling + InterDst	9	2360.35	1.40	0.21
y~log(ILL)*Dst_halo + Dst_lamp + Sampling	8	2359.72	0.77	0.28
y~log(ILL)*Dst_halo + Sampling	7	2358.95	0.00	0.42

652
 653 Df = degrees of freedom; AICc = Corrected Akaike information criterion for finite sample size; Δ AICc = (AICc
 654 of themodel)—(AICc of the best model); wi = Akaike weight (*sensu* Burnham & Anderson, 2002). See text for
 655 abbreviations of the explanatory variables.

656

657

658 **Table 2.** Estimated regression parameters and p-values according to GLM analysis. See text for
 659 abbreviations of the explanatory variables.

Variable	Estimated β	Standard Error	z-value	p-value
Intercept	-7.3130	2.675	-	-
log(ILL)	1.3224	0.254	5.201	<0.001
Dst_lamp	1.3912	0.548	2.537	0.011
log(ILL) x Dst_lamp	-0.1528	0.052	-2.291	0.003
Sampling (level: December)	-0.1816	0.137	-1.324	0.185
Sampling (level: July)	1.3761	0.138	9.979	<0.001

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667 **FIGURE CAPTIONS**

668

669 **Figure 1.** **A)** *Brigittea civica* (Lucas) (Araneae: Dictynidae) (photo credits:
670 Dr. Hans-Juergen Thorns). **B)** Sampling plot on an arcade ceiling with a reduced density of cobwebs of *B.*
671 *civica*. **C)** Sampling plot on an arcade ceiling with a significant contamination of cobwebs of *B. civica*. **D)**
672 Sampling plot on an arcade ceiling entirely covered by cobwebs of *B. civica*. **E)** The historical arcades of
673 Turin in the area close to Palazzo Carignano. Arrows point at area covered by webs of *B. civica* (Photo
674 credits: Nicola Paccagnella — www.nicola.photos).

675

676 **Figure 2.** Schematic summary of the monitoring protocol.

677

678 **Figure 3.** Maps of the studied arcades showing interpolated surfaces of the predicted coverage of webs in
679 winter (**a**), spring (**b**) and summer (**c**) according to GLM results. Size of each sampling plot is proportional to
680 the observed web coverage.

681

682 **Figure 4.** Predicted relationship between the coverage of webs of *Brigittea civica* and the intensity of artificial
683 light (log-transformed) in interaction with the distance from the incandescent historical lamppost across the
684 three sampling sessions. To generate the predictions, two arbitrary values of distance from the incandescent
685 lamppost were used, namely zero (filled line) and six (dashed line) meters. Shaded grey surfaces are 95%
686 confidence intervals.

687

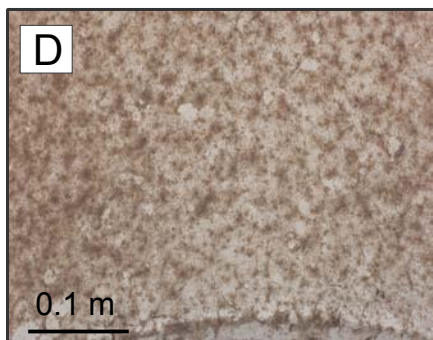
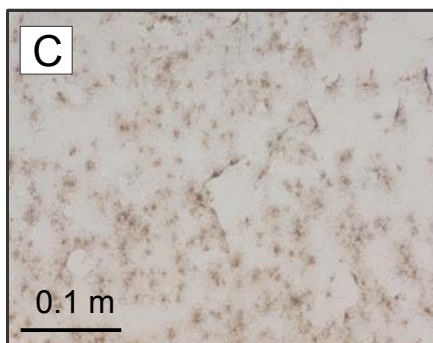
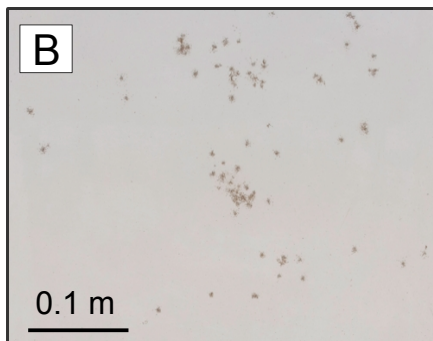


Figure 2

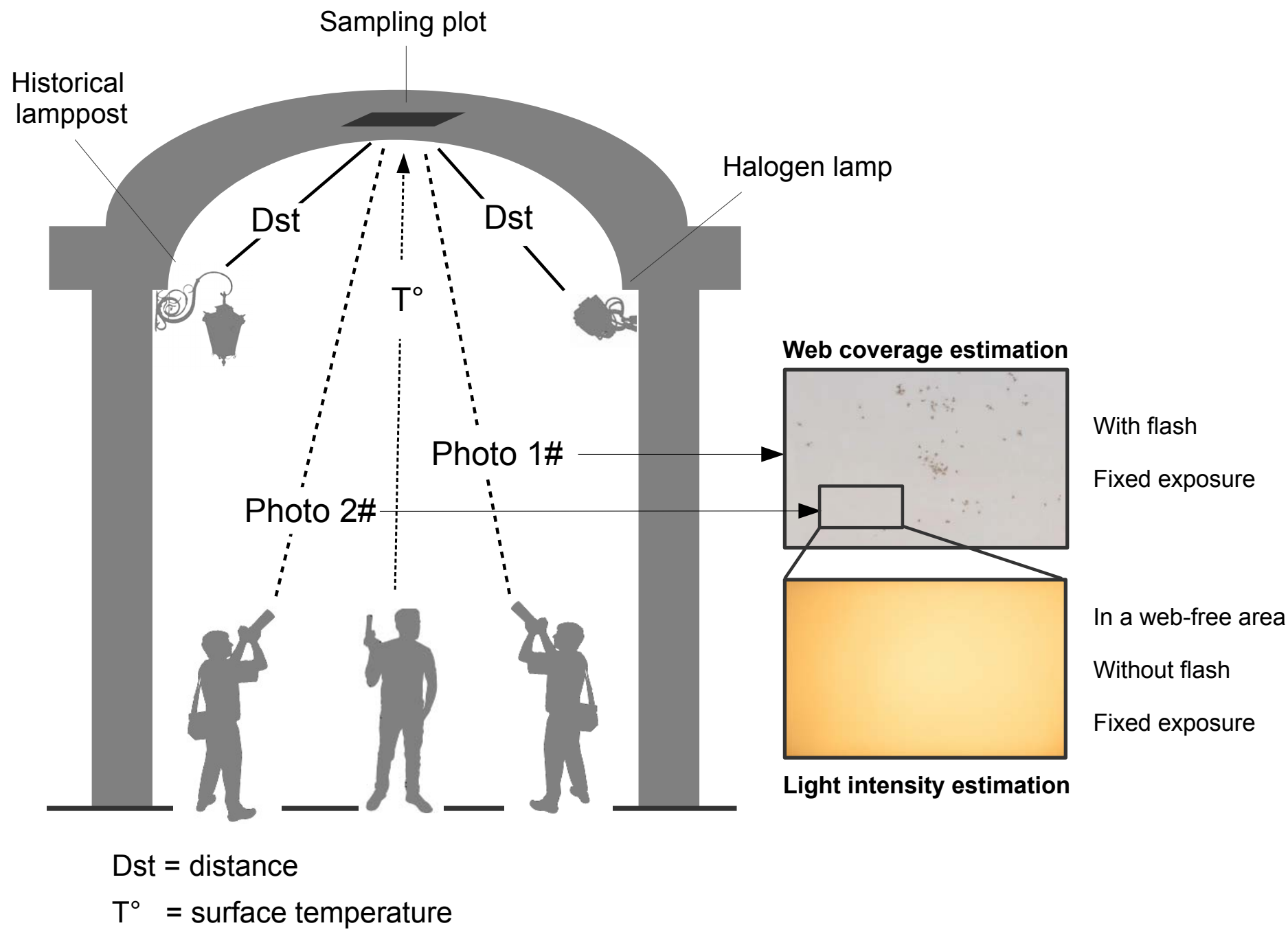


Figure 3

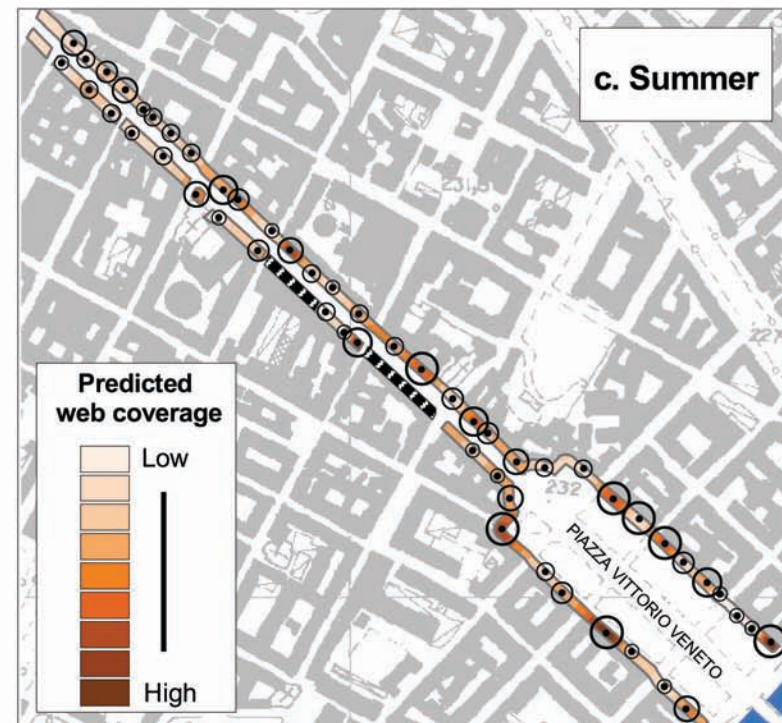
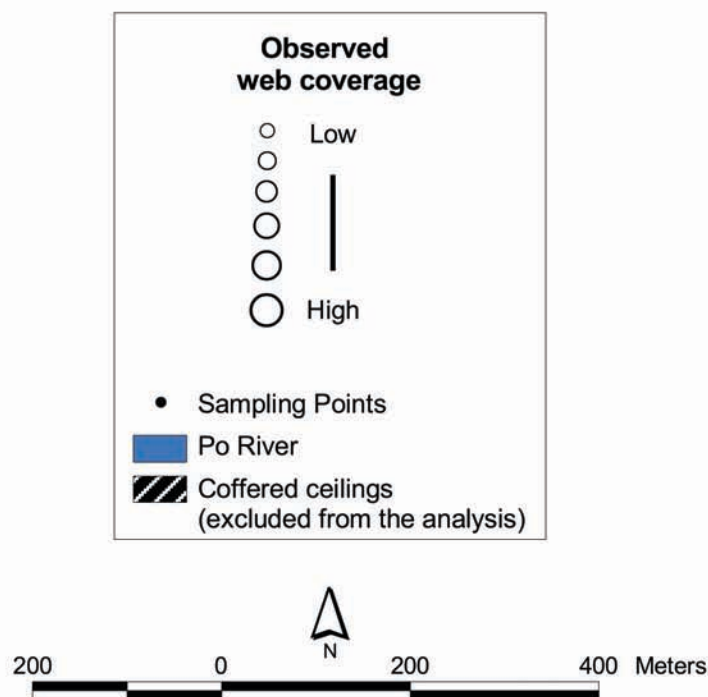
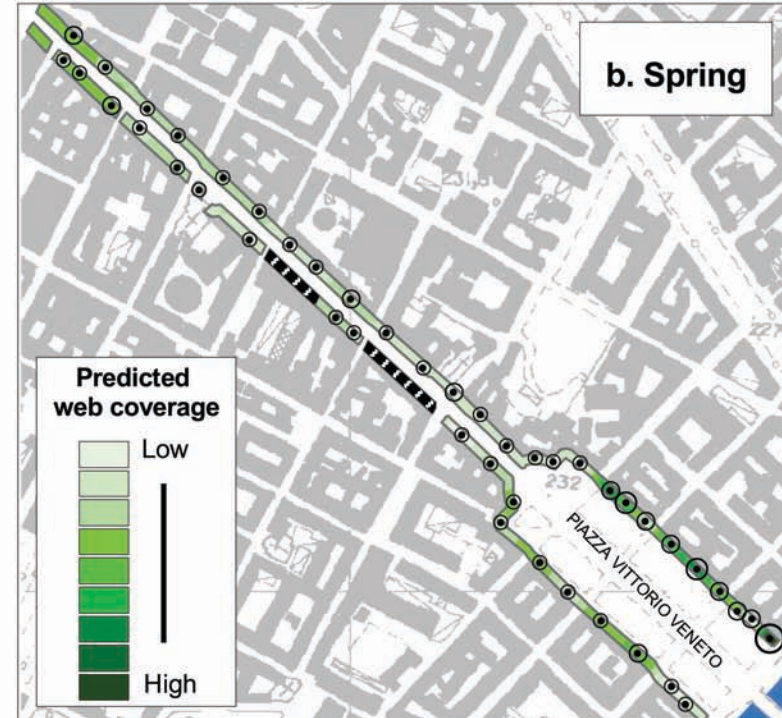
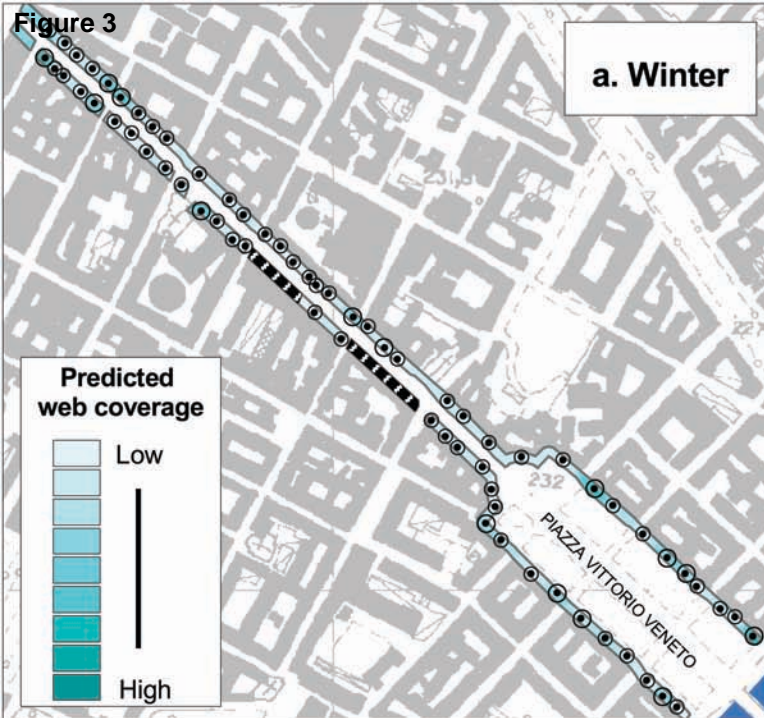
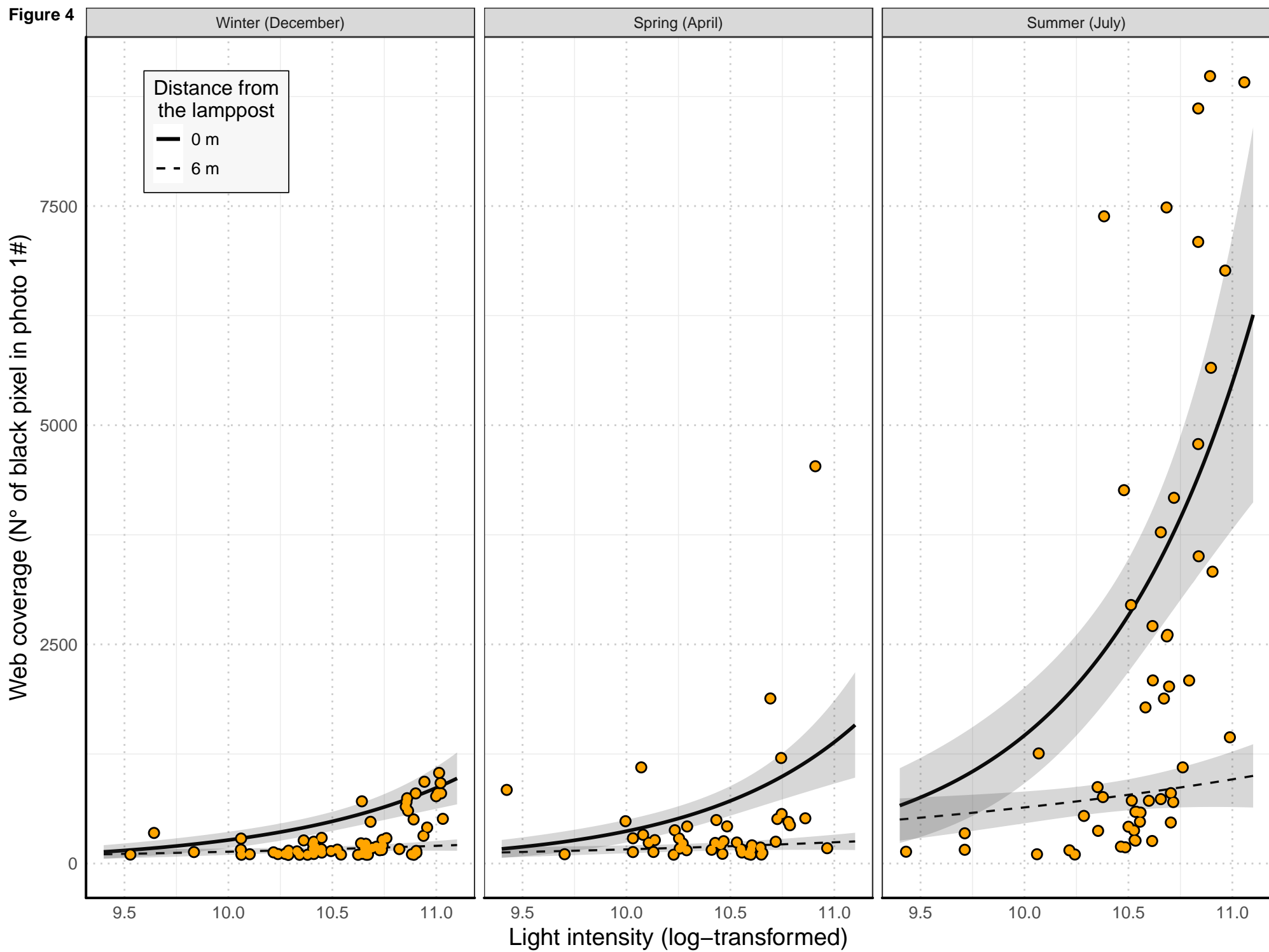
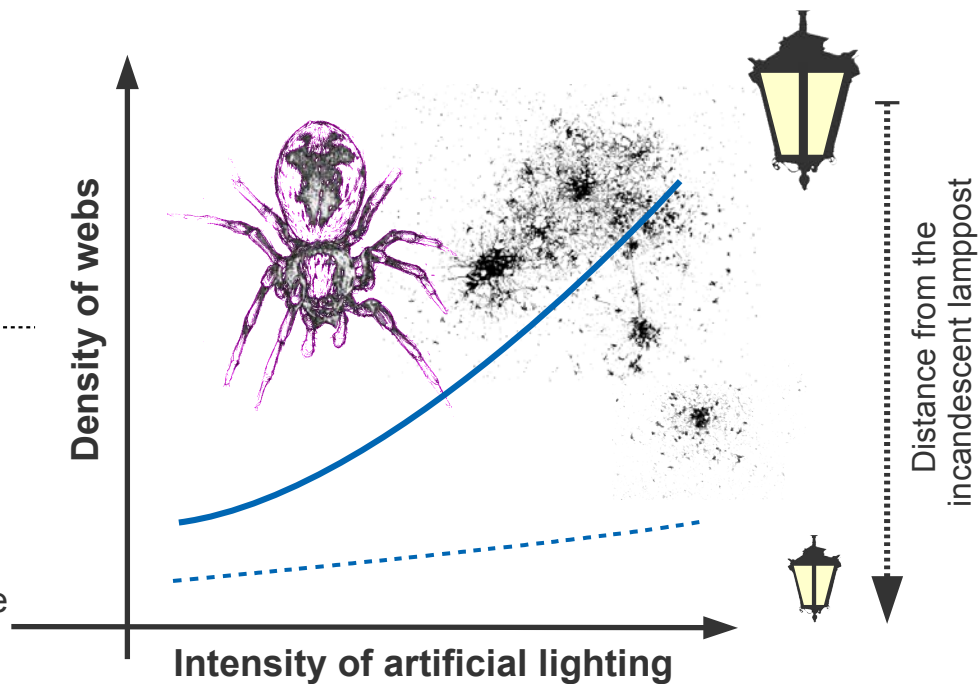
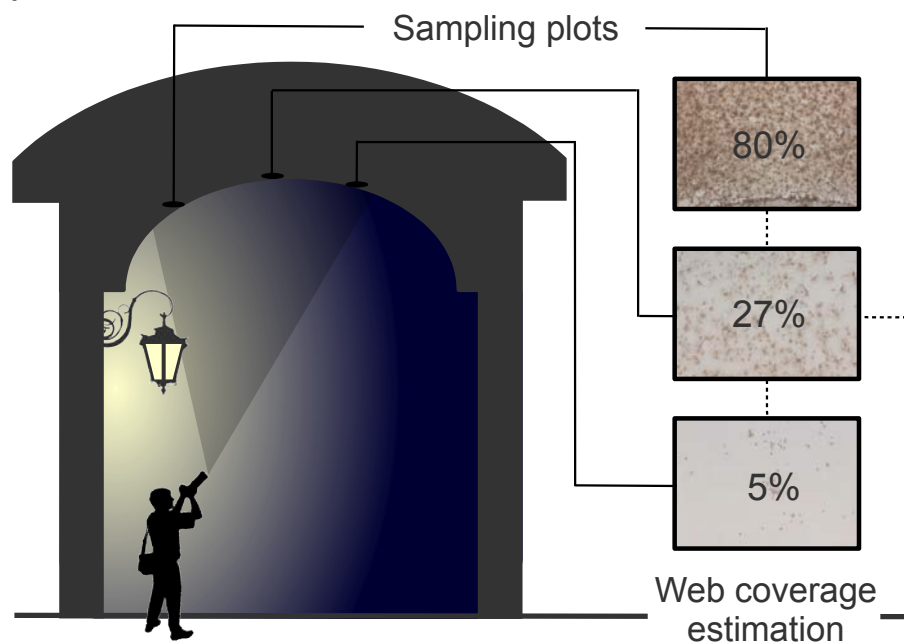


Figure 4

Graphical Abstract



1 **ACKNOWLEDGMENTS**

2

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8